Updates on Simulation of Noise Effects in the Presence of Beam-Beam Interactions

Ji Qiang

Center of Beam Physics

Lawrence Berkeley National Laboratory

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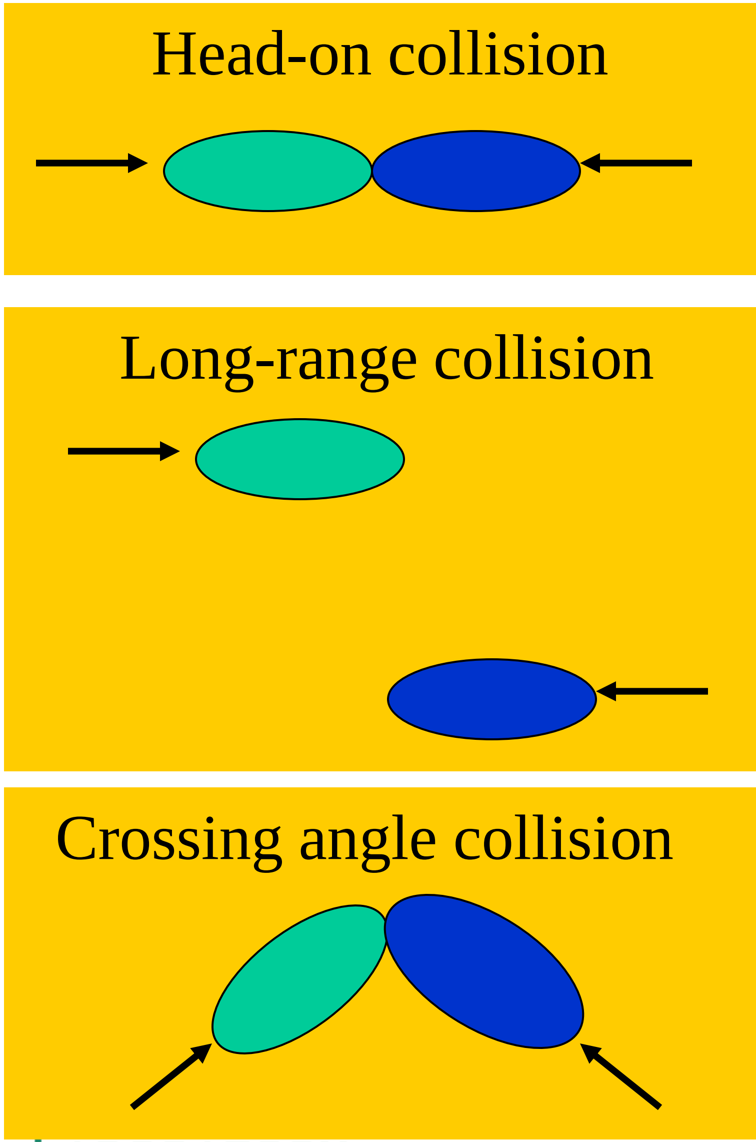
Introduction

- Benchmark of noise simulation with analytical solution
- Simulation of crab cavity noise

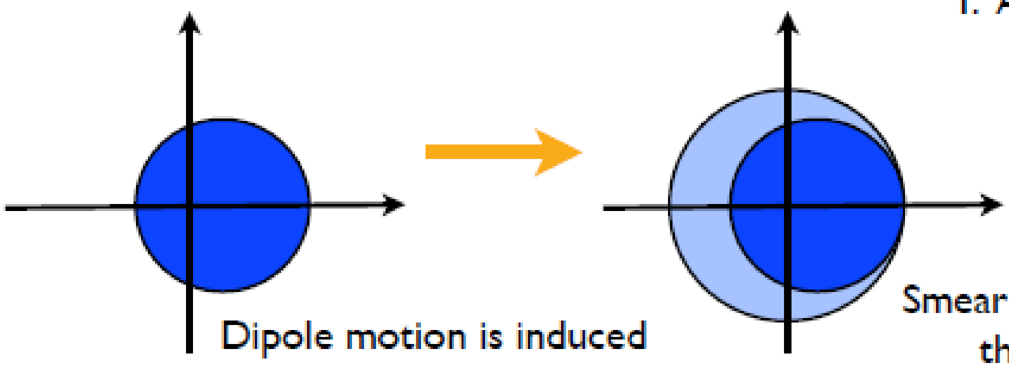
BeamBeam3D:
A Parallel Colliding Beam Simulation Code

- Multiple-slice model for finite bunch length
- New algorithm -- shifted Green function -- efficiently models long-range collisions
- Parallel particle-field based decomposition to achieve perfect load balance
- Lorentz boost to handle crossing angle
- Arbitrary closed-orbit separation
- Multiple bunches, multiple collision points
- Linear transfer matrix + one turn chromaticity
- Conducting wire, crab cavity, e-lens compensation model
- Feedback model
- Impedance model
- Soft-Gaussian model



Analytical Model of White Noise Induced Emittance Growth in Colliding Beams

Y. Alexahin, NIM A391,73 (1996)



Dipole motion is induced by offset collision

Smear out of the dipole motion, then emittance growth

0

$$\frac{1}{\varepsilon_0}\frac{d\varepsilon_x^{(1,2)}}{dN} = \frac{1-s_0}{4}\left(\Delta^2 + g^2\Delta_{\mathrm{BPM}}^2\right) S(g/2\pi|\xi|)\,. \qquad (9)$$

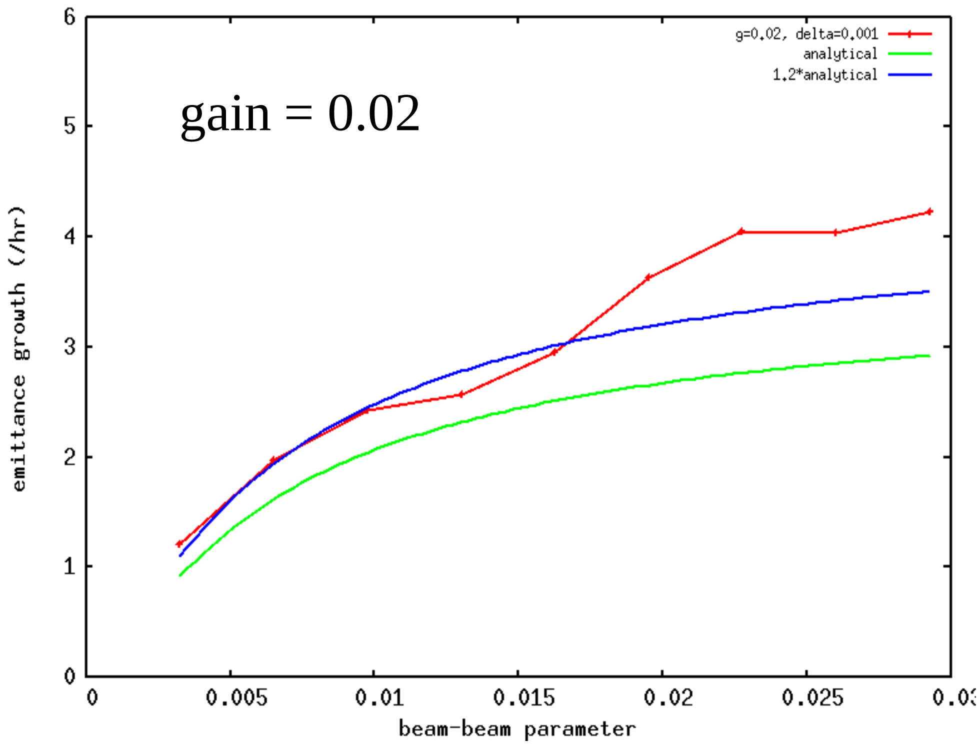
with $S(x) \approx \dfrac{1}{(1+x)^2}$ $\qquad s_0 \equiv s(\lambda_0) \approx 0.645,$ $\qquad \Delta = \dfrac{\delta x}{\sigma_x}$

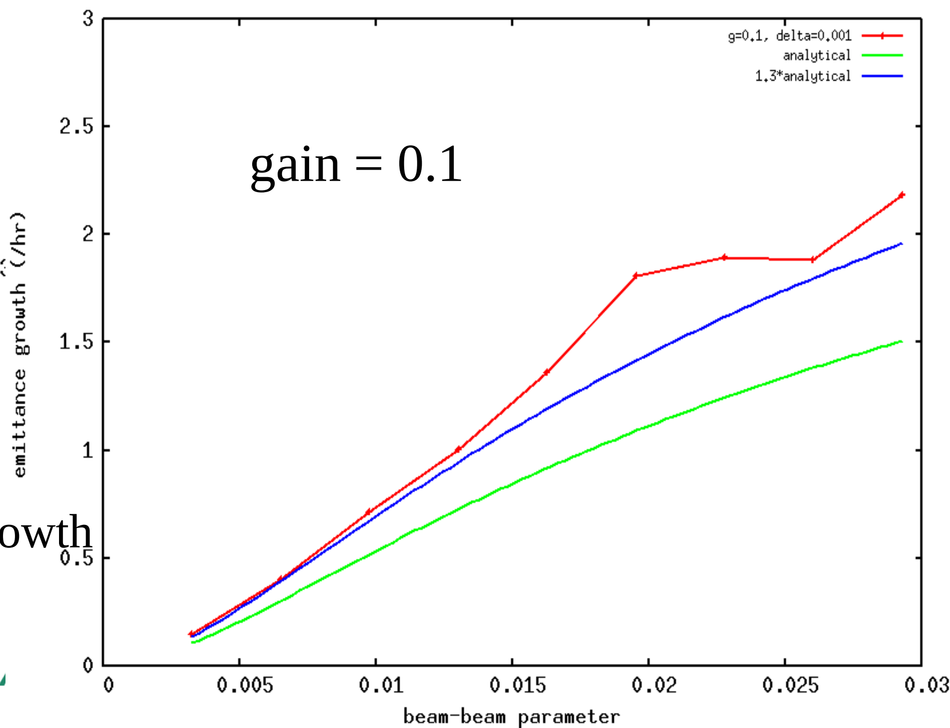
beam-beam parameter

Some Physical Parameters Used in the Simulations

Physical parameters	
ε (normalized)	3.75 um
pick-up gain	0.02-0.1
Tunes Chromaticity	64.31/59.32 0
*β** Θ	50 cm 0.0 mrad
ξ_tot *N* IPs	0.003-0.03 $1. - 9\text{x}10^{11}$ 1

Emittance Growth Rate vs. Beam-Beam Parameter
(Simulation vs. Analytical Solution)



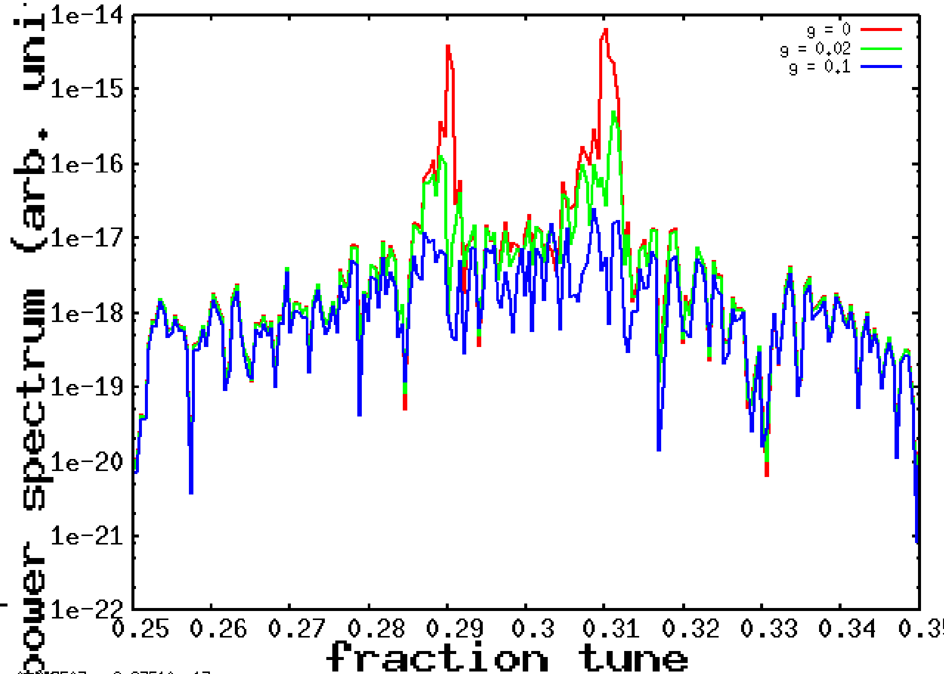


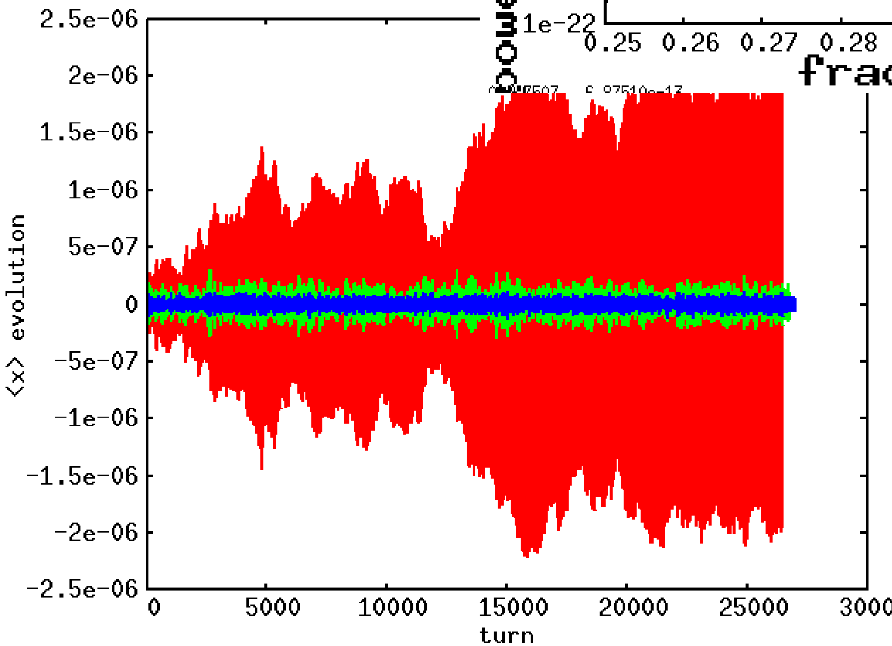
- good agreement between simulation and with small beam-beam parameter
- difference might be related resonance driven growth

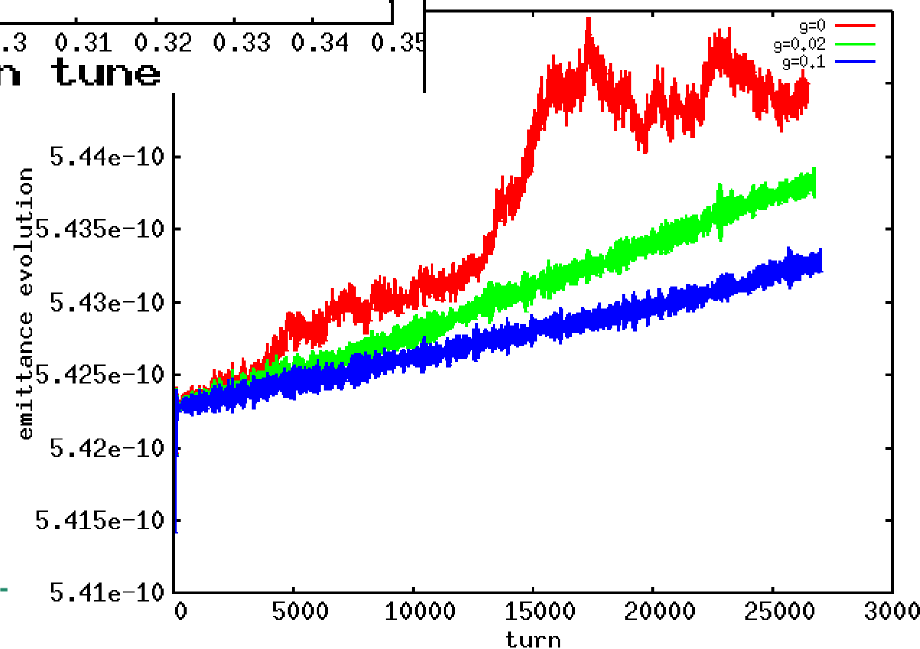
Thanks Javier for the beam parameters

Horizontal Power Spectral, Emittance, Centroid Evolution

(with different gains, beambeam param. = 0.016)







RF Noise in the Crab Cavity Causes Emittance Growth and Luminosity Degradation

$$x_i \propto V_{cc} \sin(kz_i + \delta\varphi)$$

0th order error (phase error): $\delta X = -\frac{c}{\omega_{cc}} \tan\left(\frac{\theta}{2}\right) \delta\varphi$

1st order error (voltage error): $\delta x_i \propto \delta V_{cc} \sin(kz_i) \approx \delta V_{cc} k z_i$

white noise offset collision drives emittance growth

$$\frac{\delta\varepsilon}{\varepsilon} \approx \frac{K}{\left(1 + \frac{G}{2\pi|\xi|}\right)^2} \frac{\delta x^2}{\sigma_x^2}$$

$$\frac{\Delta L}{L} = 10.8\left(\xi \frac{\Delta x}{\sigma}\right)^2$$

G. Stupakov, SSC-560 (1991).
T. Sen and J. Ellison, PRL 77, 1051 (1996) Y. Alexahin, NIM A391,73 (1996)
K. Ohmi, in Proc. Beam-Beam 2013 workshop.

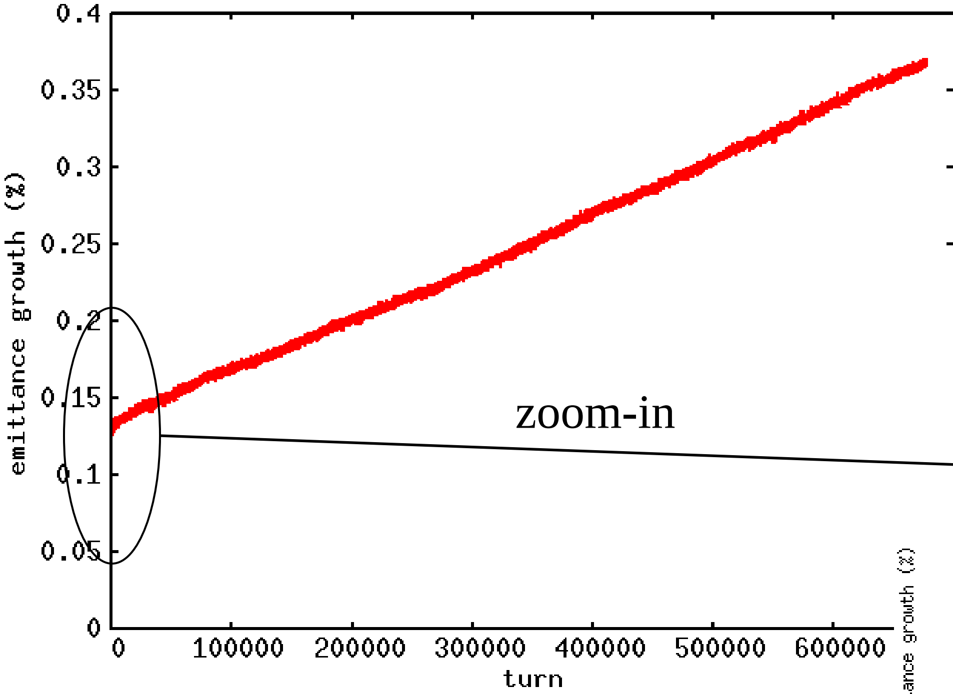
Some Physical Parameters Used in the Simulations

Physical parameters	
ε (norm.)	2.5 um
pick-up gain	0.05/0.05
Tunes Chromaticity	62.31/60.32 0 – 4
*β** Θ	15-60 cm 0.59 mrad
ξ_tot *N* IPs	0.011 - 0.022 1.1 - 2.2x10^{11} 2

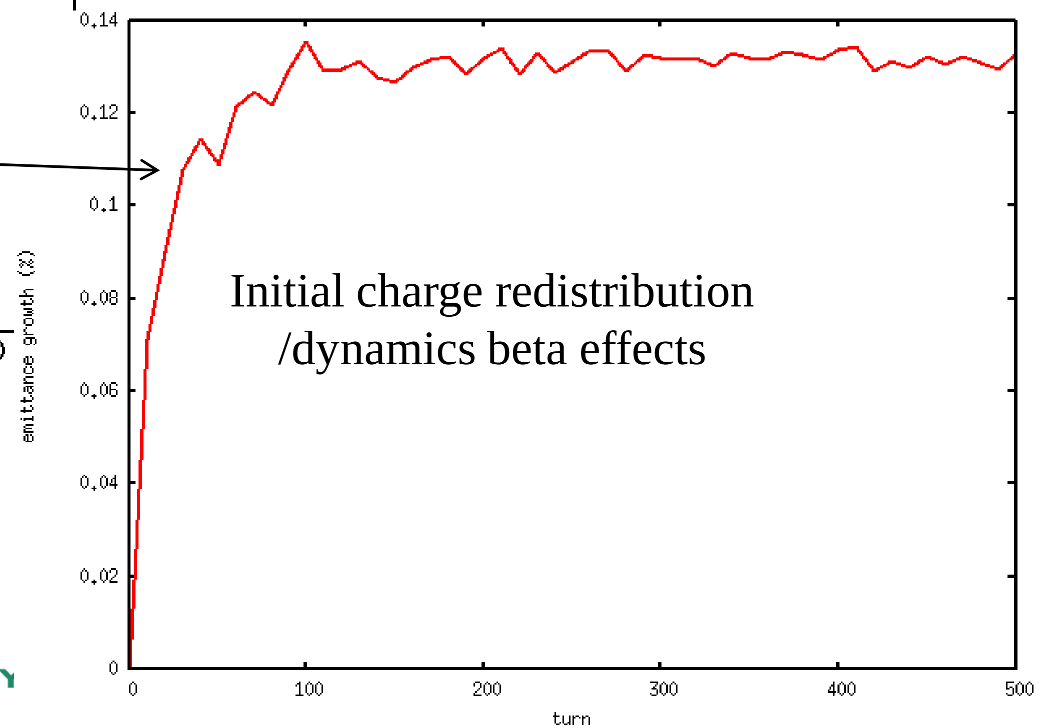
Emittance Blow-up due to Phase or Voltage White Noise

Np = 2.2 x 10^{11}, beta* = 0.49 m

emittance blow-up from voltage error 5e-5.



zoom-in

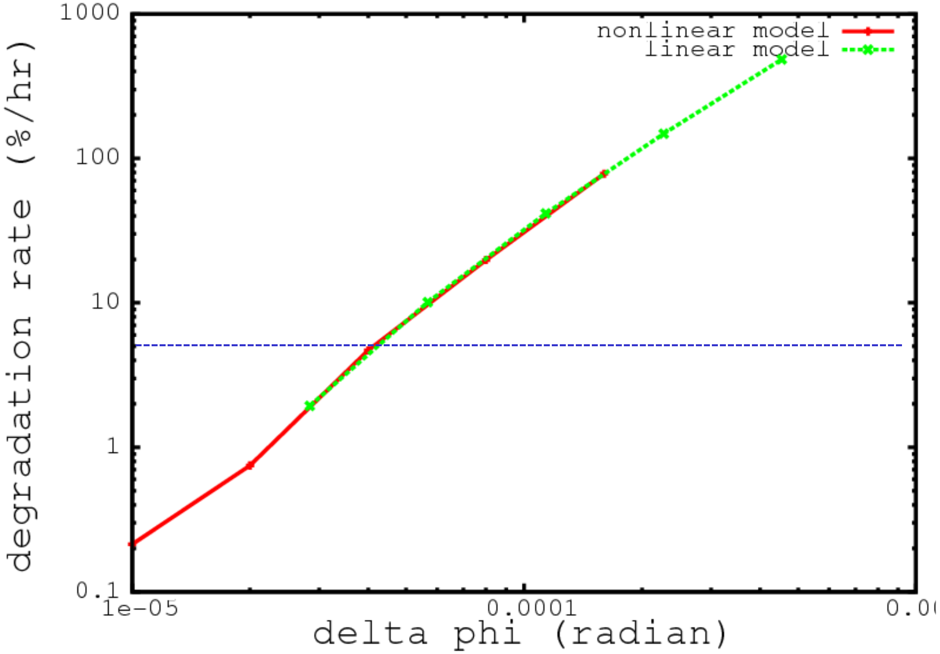


Initial charge redistribution
/dynamics beta effects

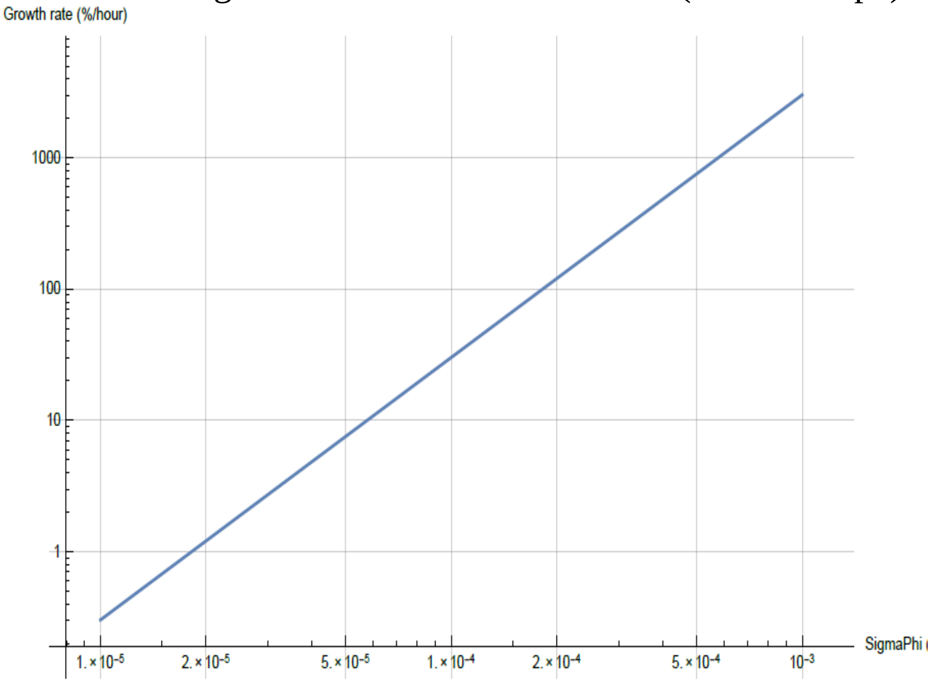
Luminosity Degradation due to Phase White Noise

degradation rate vs. phase noise amp.

simulation



P. Baudrenghien and T. Mastoridis model (from Phillipe)

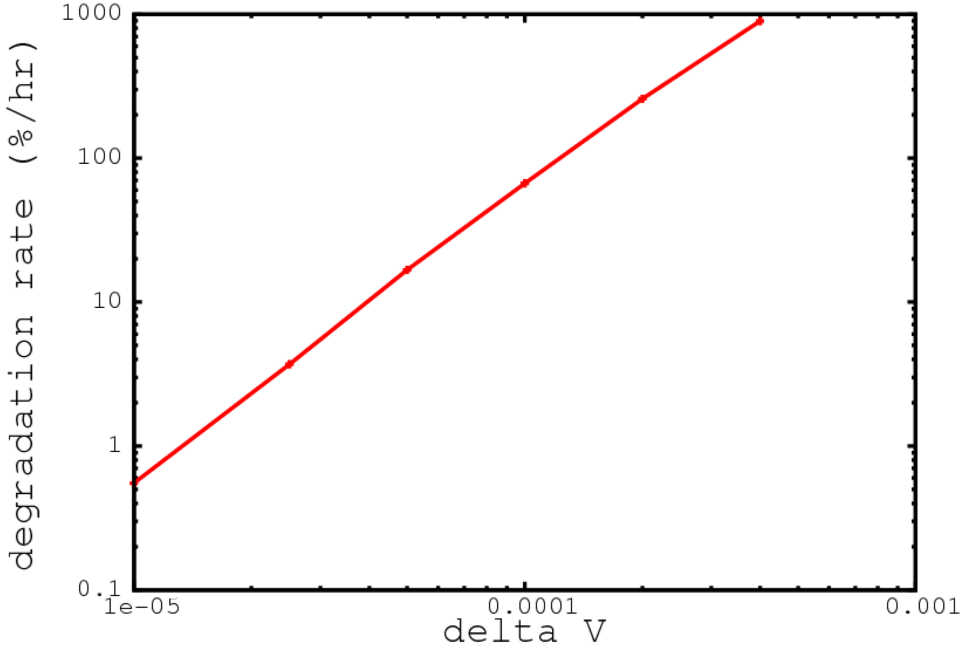


In order to have a good luminosity lifetime ~ 20 hours,
the noise amplitude needs to be kept below the level of a few 10^{-5}.

Luminosity Degradation due to Voltage White Noise

degradation rate vs. voltage noise amp.

simulation



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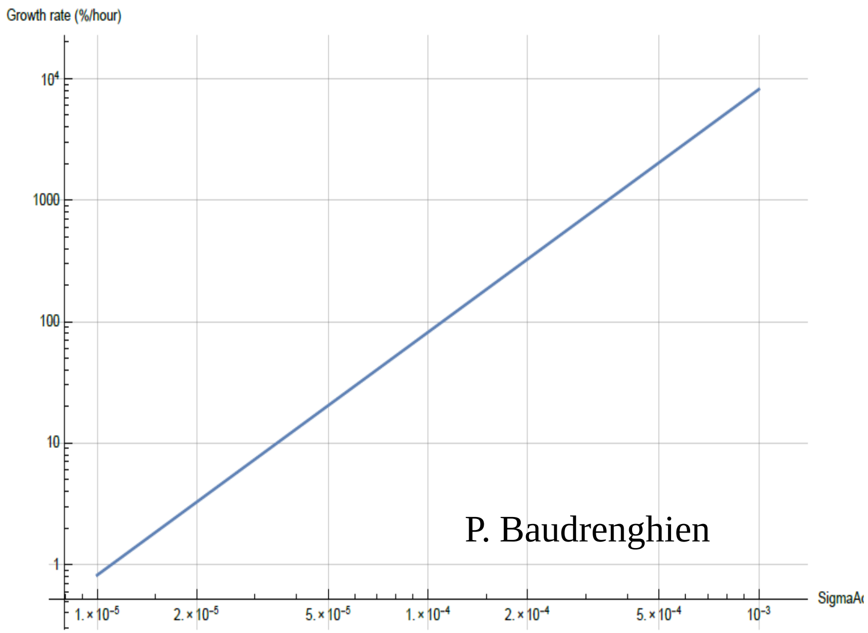
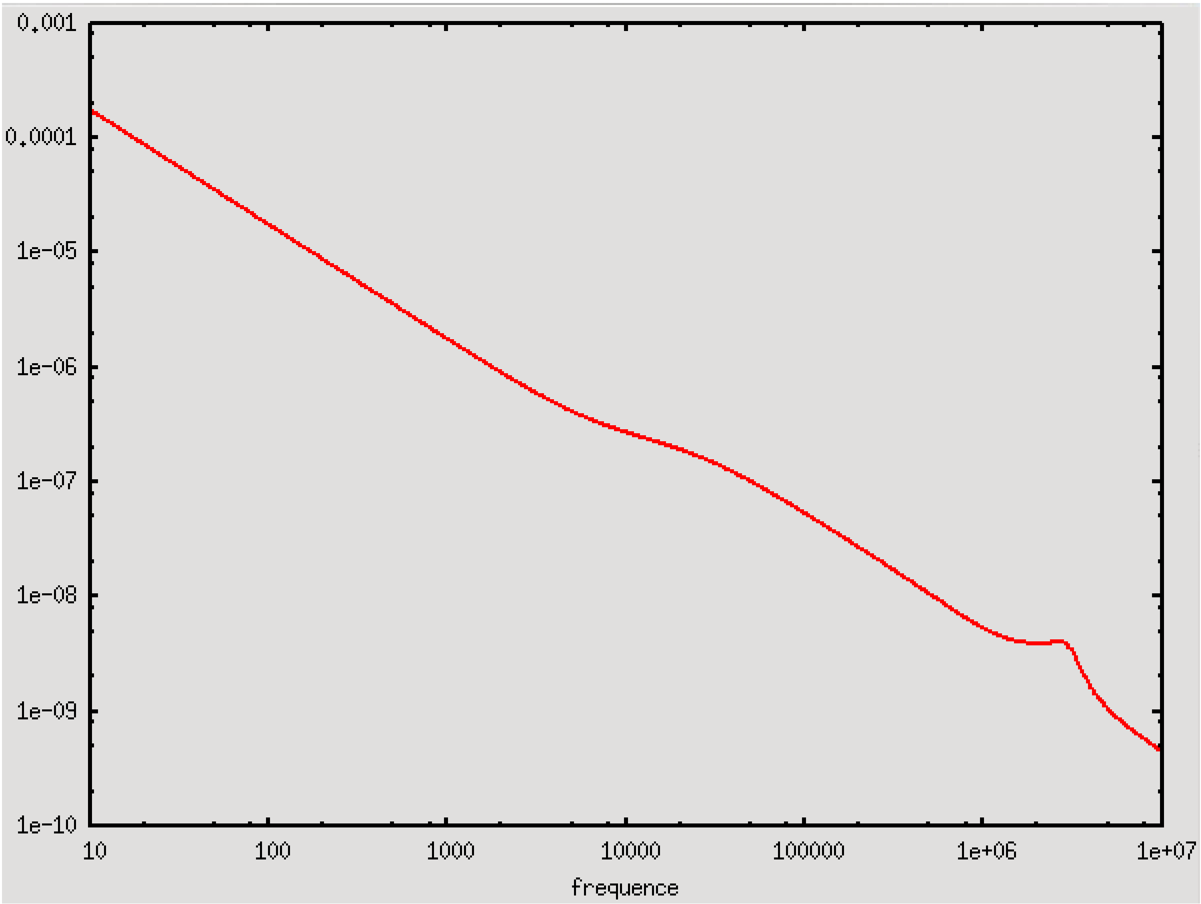


- Good agreement between the simulation and the model
- Need detailed comparison and understanding

Frequency-Dependent Crab Cavity Noise Power Spectrum

(dBc/Hz)

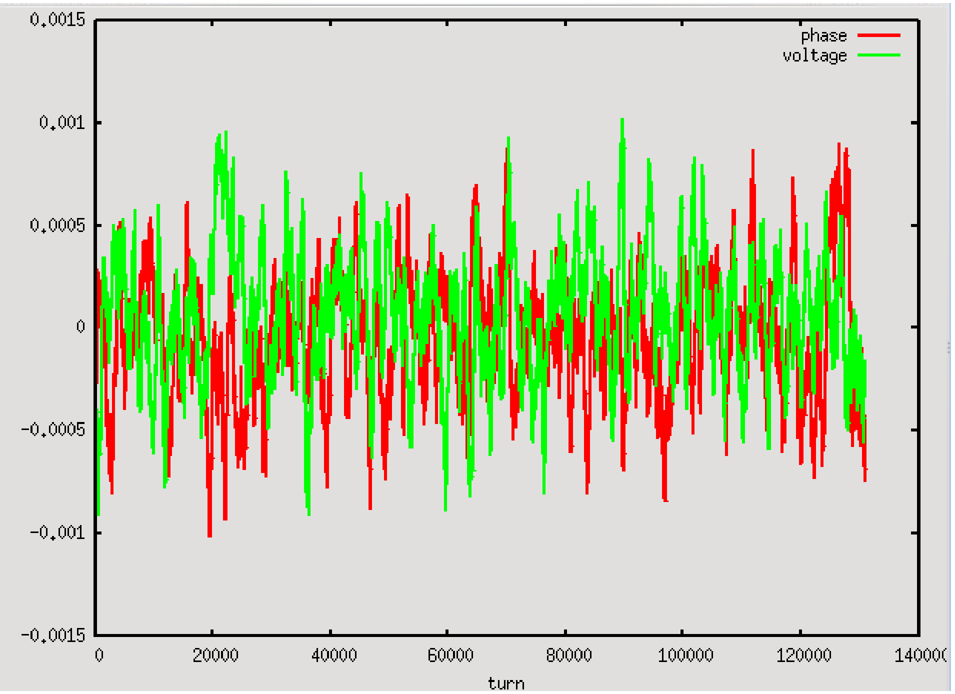


frequency (Hz)

Courtesy of T. Mastori

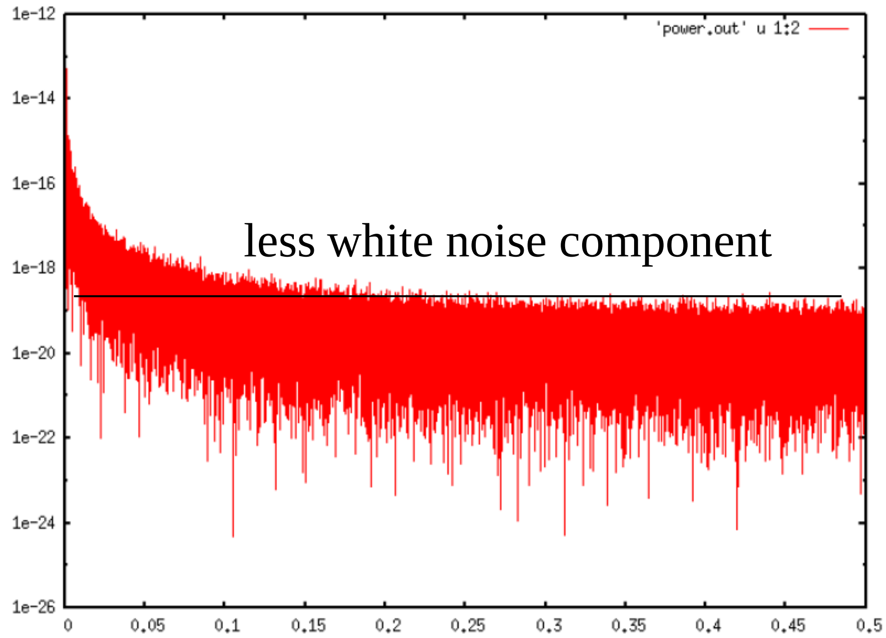
Crab Cavity Noise in Time Domain

Nominal RMS Amplitude ~ 3×10^{-4}



turn

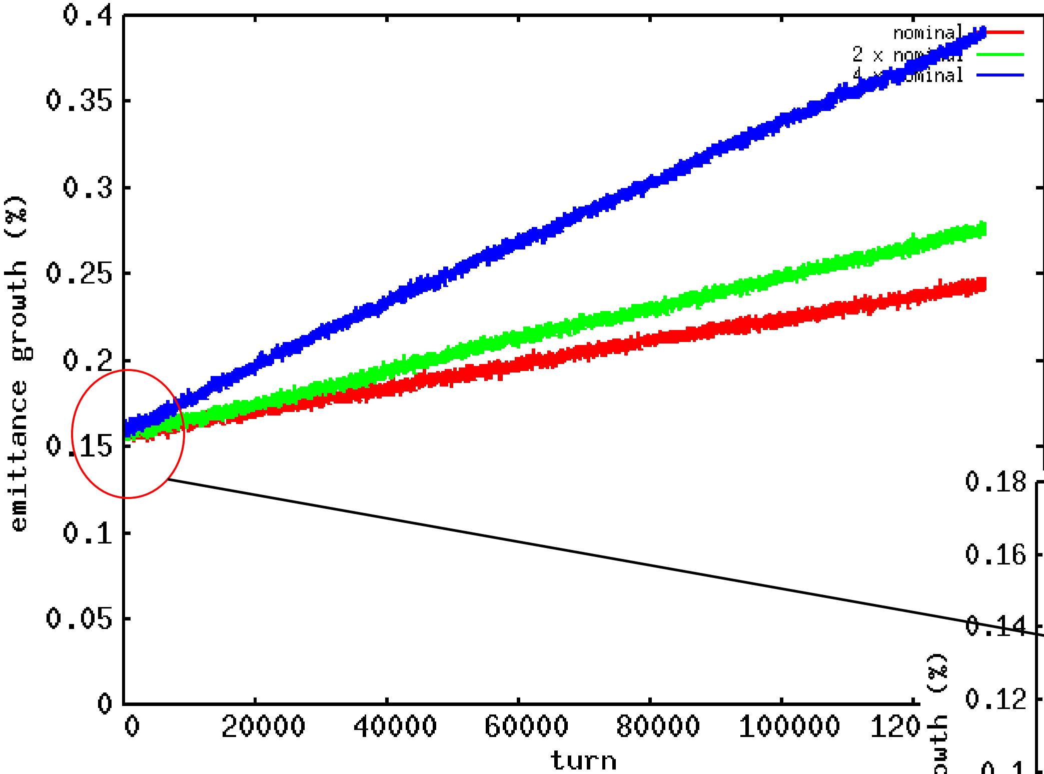
spectrum

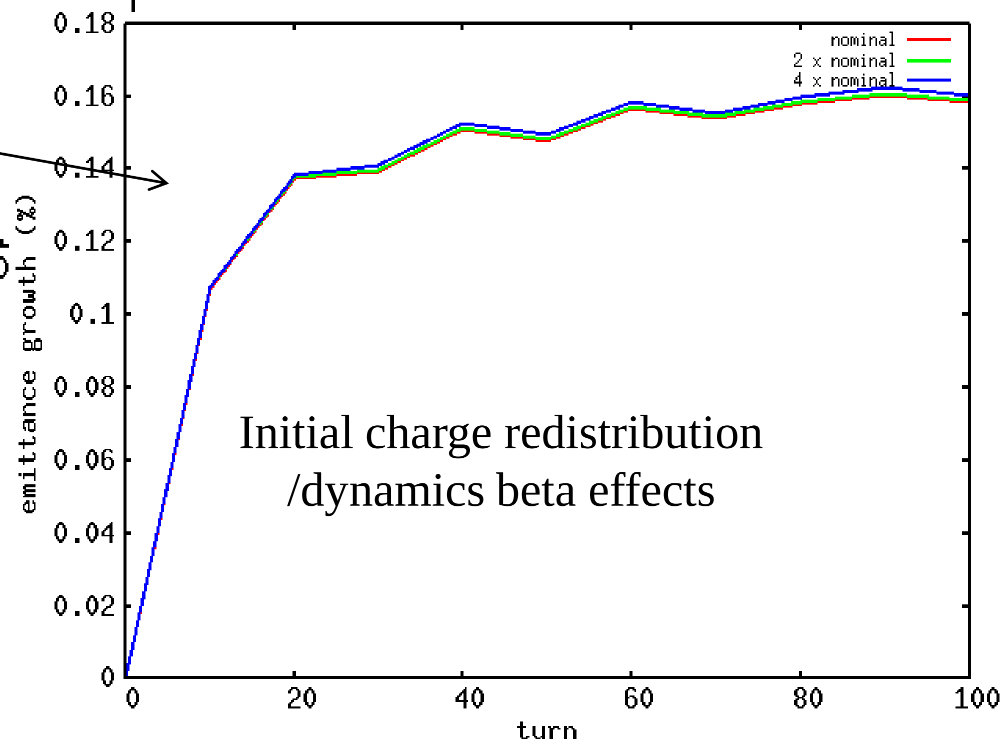


there are additional 14 turn-dependent noise similar to the above ones

RMS Emittance Evolution with Different Noise Amplitudes

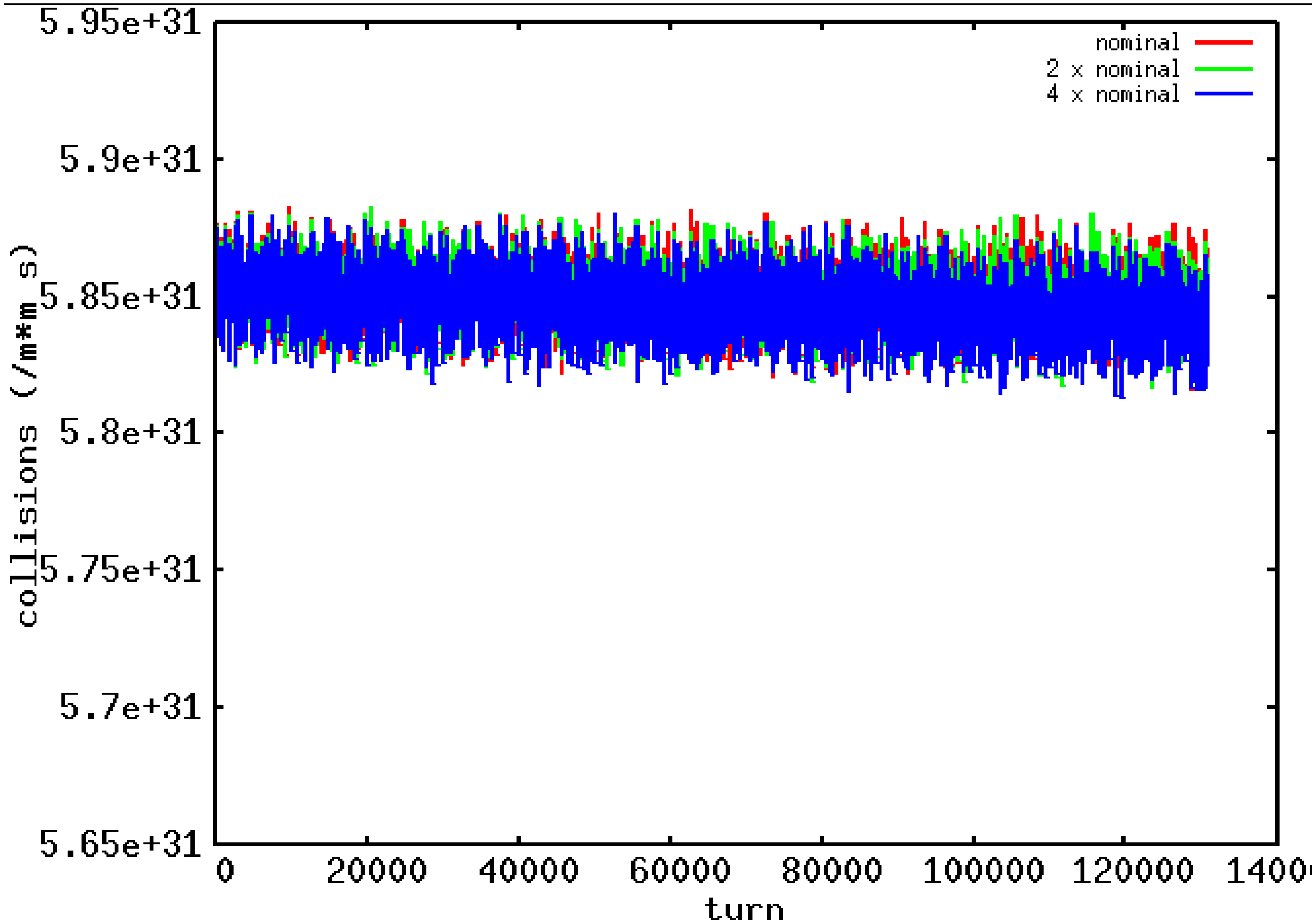
Np = 2.2 x 10^{11}, beta* = 0.15 m





Peak Luminosity Evolution with Different Noise Amplitudes

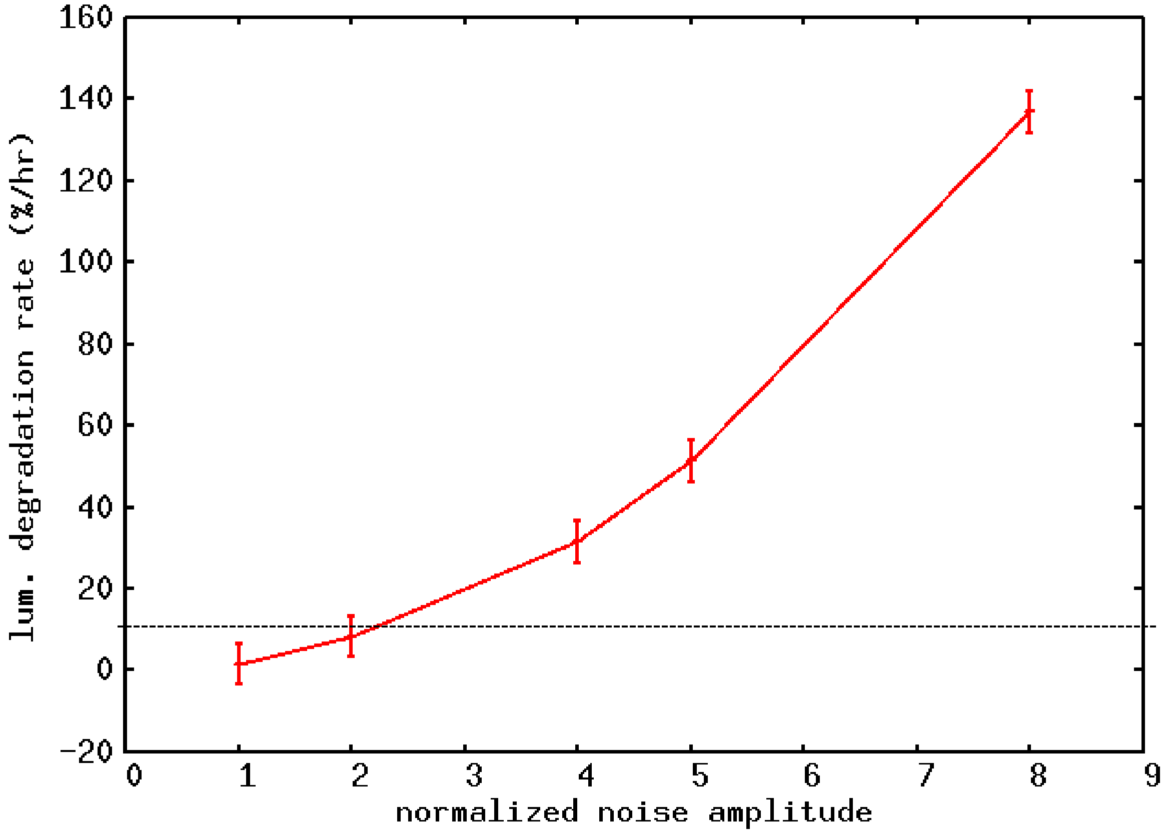
Np = 2.2 x 10^{11}, beta* = 0.15 m



CC Noise Induced Lumi. Degradation with Different Intensities

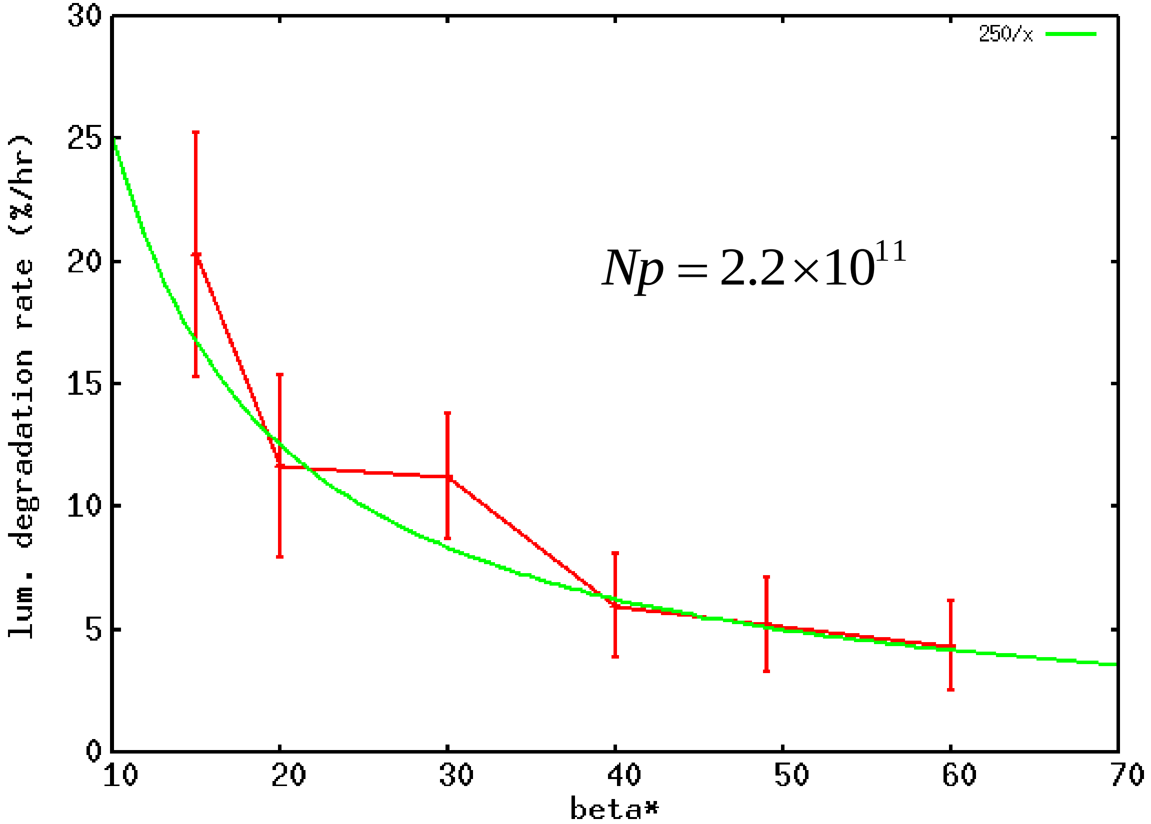
beta* = 0.15 m

$Np = 2.2\times10^{11}$



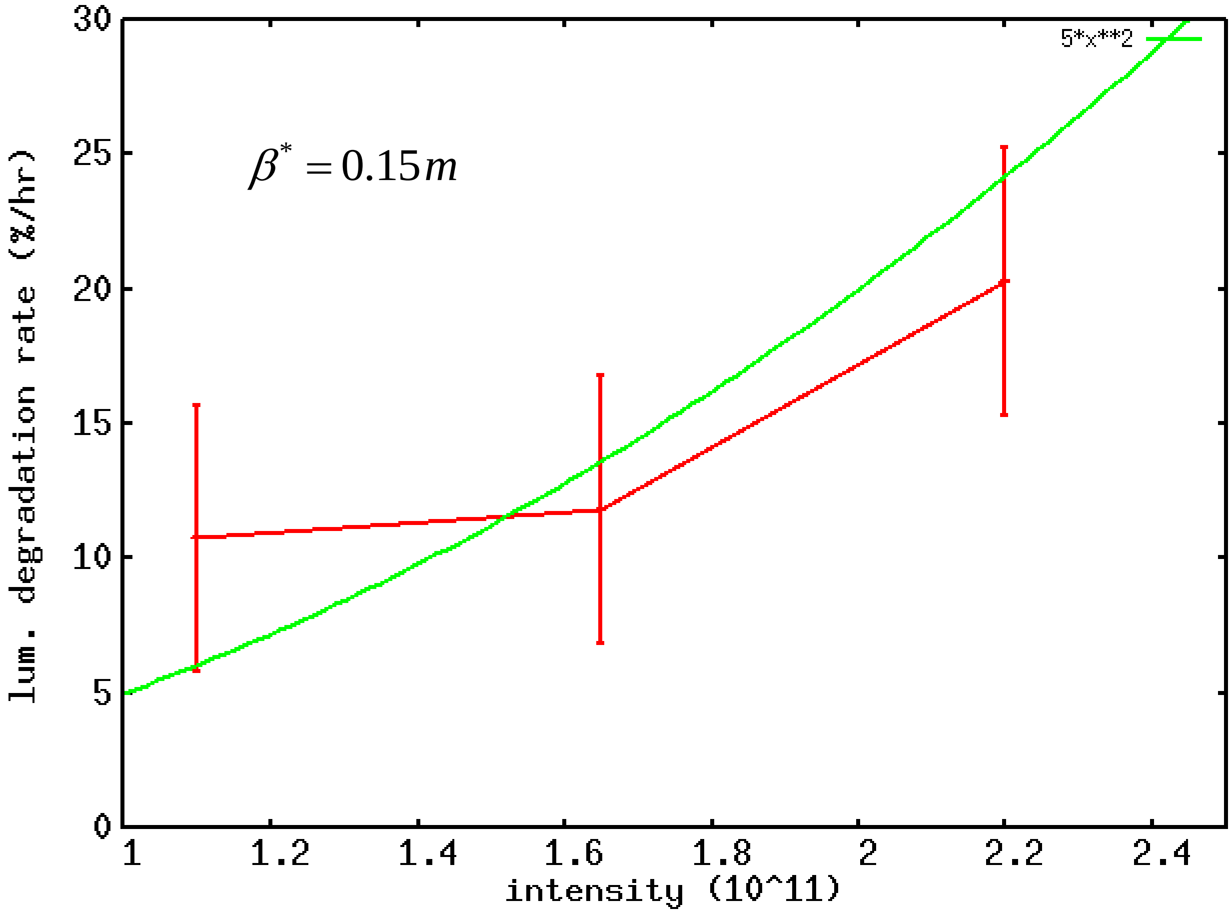
RMS noise amplitude needs to be kept below 2 x nominal value
in order to have a good luminosity lifetime

CC Noise Induced Lumi. Degradation with vs. beta*
(with nominal noise amplitude)



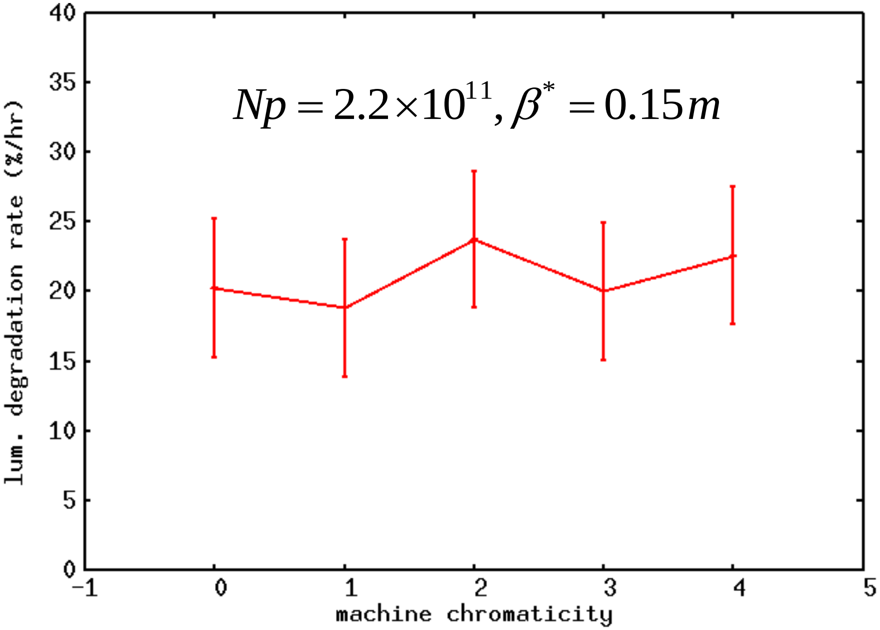
❖ strong dependence on the beta*

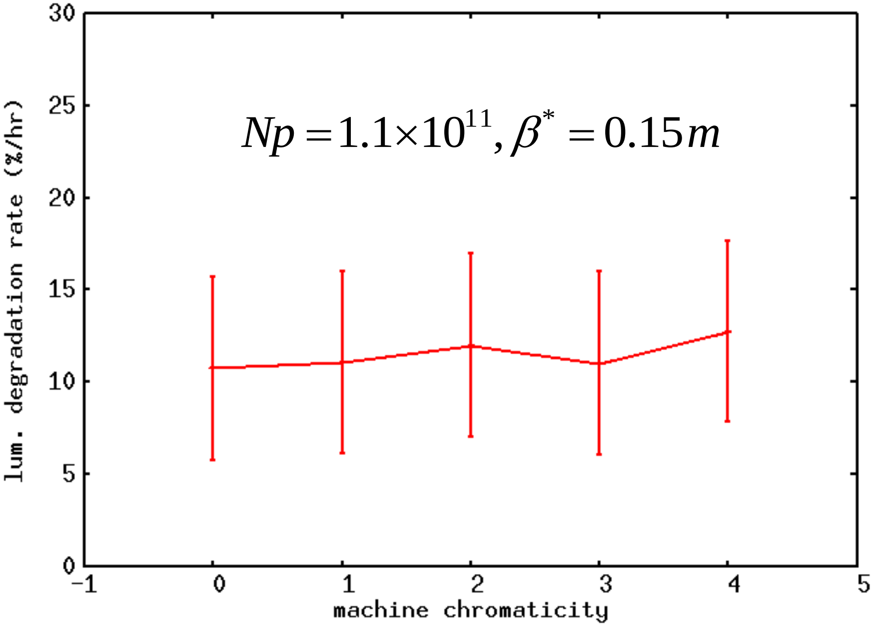
CC Noise Induced Lumi. Degradation with vs. Intensity
(with nominal noise amplitude)



❖ weaker dependent on the bunch intensity

Lumi. Degradation with Different Chromaticities
(and with nominal CC noise amplitude)





❖ not sensitive to the machine chromaticity

Conclusions

- Phase and voltage noise error in crab cavity can cause significant luminosity decrease.
- For the phase and voltage amplitude noise, the tolerance level for 1 day luminosity lifetime is about a few x10^{-4} radian, which is about a factor 10 larger than the tolerance level of the pure white noise error.
- Luminosity degradation rate has strong dependence on the beta* at IPs, weaker dependence on bunch intensity, and not sensitive to machine linear chromaticity and machine stable working point.

Thank You!